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RESEARCH MEMORANDUM

COMPARISON OF EFFECTS OF AILERONS AND COMBINATIONS OF SPOILER-SLOT-DEFLECTOR ARRANGEMENTS ON SPIN RECOVERY OF SWEPTBACK-WING MODEL HAVING MASS DISTRIBUTED ALONG THE FUSELAGE

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been made in the Langley 20-foot free-spinning tunnel to determine the effect of lateral-control systems employing various combinations of spoilers, slots, and deflectors as compared with ailerons on the spin-recovery characteristics of a model of a 35° swept-wing fighter loaded heavily along the fuselage.

The results of the investigation indicated that ailerons were favorable for recovery when they were deflected full with the spin. A spoiler-slot-deflector arrangement for lateral control at 70 percent of the wing chord was effective in assisting the recovery when it was deflected against the spin, but a similar arrangement at 50-percent chord was ineffective. Upper-surface spoilers alone or in combination with a slot offered little assistance in terminating the spins.

INTRODUCTION

Results of the model tests in the Langley 20-foot free-spinning tunnel have indicated that in many cases the recovery from spins of high-speed swept-wing airplanes having mass distributed primarily along the fuselage is dependent on the application of a rolling moment in the direction of the spin (ref. 1). Conventional trailing-edge ailerons positioned on the outboard portion of the wing have generally proved adequate in providing the required rolling moment at spinning attitudes for the termination of the spin; however, the use of spoiler-slot-deflector lateral controls for high-speed airplanes has recently been proposed. Static force tests on typical controls of this type are discussed in references 2 and 3. As the effect of spoilers, slots, and deflectors in spins had not been previously studied, an investigation was undertaken in the Langley 20-foot free-spinning tunnel to determine the relative effectiveness in terminating spins of conventional ailerons and several flap-type spoiler and deflector arrangements with and without wing slots. The results of the investigation are presented herein. The model used for the investigation had a 35° sweptback wing and was representative of current fighter designs except that the nose was shortened to provide for relatively steady spins (ref. 1) and consistent recoveries so that the effect of the ailerons and the various spoiler-deflector arrangements would be more readily observable. The controls located at two different positions were investigated and the results were compared with those of conventional outboard ailerons.

SYMBOLS

b	wing span, ft
c	wing chord at any station along span, ft
$\bar{c}$	mean aerodynamic chord, ft
m	mass of airplane, slugs
S	wing area, sq ft
$x/\bar{c}$	ratio of distance from center of gravity rearward of mean-aerodynamic-chord leading edge to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line and mean aerodynamic chord (positive when center of gravity is below reference line)
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

ρ air density, slugs/cu ft

μ relative density of airplane, $m/\rho Sb$

α angle between fuselage reference line and vertical axis (approximately equal to the true angle of attack at plane of symmetry), deg

ϕ angle between span axis and horizontal axis, deg

V full-scale true rate of descent, ft/sec

Ω full-scale angular velocity about spin axis, rps

APPARATUS AND METHODS

Model

The model used for the investigation was constructed principally of balsa and the spoilers and the deflectors were made of thin sheet aluminum. The model was considered a 1/24-scale model of a current swept-wing fighter airplane. A three-view drawing of the model tested is shown in figure 1. Details of the two arbitrarily chosen spoiler and deflector configurations A and B are shown in figures 2 and 3. As is indicated in figures 2 and 3, the spoiler was a flap type of upper-surface control hinged at its leading edge, whereas the deflector was a flap type of lower-surface control hinged at its trailing edge. The dimensional characteristics of the assumed full-scale airplane are presented in table I.

The model was ballasted to obtain dynamic similarity to an airplane at an altitude of 15,000 feet (ρ = 0.001496 slug/cu ft). A remote-control mechanism was installed in the model to actuate the controls for the recovery attempts. Sufficient torque was exerted on the controls for the recovery attempts to deflect the controls fully and rapidly.

WIND TUNNEL AND TESTING TECHNIQUE

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is, in general, similar to that described in reference 4 for the Langley 15-foot free-spinning tunnel, except that the model launching technique has been changed. The present models are launched by hand into the vertically rising airstream with the controls set in the desired position. The airspeed is adjusted until the upward force of the air balances the weight of the model and, after a number of turns in the established spin, recovery is attempted by movement of the controls. After recovery or after the test is completed, the model dives or is lowered into a safety net. The model is retrieved, the controls reset to the desired positions, and the next spin is made. A photograph of the model in a spin is shown in figure 4.

The spin data presented were converted to corresponding full-scale values by the methods described in reference 4. As previously indicated, the spin of the unmodified model was in many cases violently oscillatory so that inconsistent recoveries that would obscure the effect of the controls were obtained; and therefore, the model was altered to obtain a less oscillatory spin and fairly consistent recoveries. The turns for recovery were measured from the time the controls were moved to the time the spin rotation ceased. For the spins which had a rate of descent in excess of that which can be attained readily in the tunnel, the rate of descent was recorded as greater than the tunnel airspeed at the time the model hit the safety net, for example, >326 fps. For these tests, the recovery was attempted before the model reached its final attitude and while the model was still descending in the tunnel. Such results are conservative; that is, the recoveries will not be as fast as those obtained when the model is in the final steeper attitude. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, for example, >3. A >3-turn recovery, however, does not necessarily indicate an improvement over a >7-turn recovery. For recovery attempts in which the model did not recover after 10 turns, the recovery was recorded as ∞. When the model recovered without the control movement with the rudder set with the spin, the result was recorded as "no spin." In some cases steady-spin data were omitted on the charts because the spins were either too oscillatory or had too high a rate of descent to permit obtaining the data.

The spin-tunnel tests reported herein were made to determine the spin and recovery characteristics of the model at the normal spinning control configuration (elevator full up, lateral controls neutral, and rudder full with the spin) and with the lateral controls deflected full with and full against the spin. For the present tests, recovery was generally attempted by rudder neutralization. (Normally, recoveries are attempted by full rudder reversal, but in this instance, rudder neutralization was utilized in order to accentuate the effect of lateral-control positioning on recoveries.) A few recovery attempts were also made by simultaneous rudder neutralization and movement of the spoiler-slot-deflector controls to full against the spin. Recoveries were considered satisfactory if the recovery occurred within $2\frac{1}{4}$ turns or less after the control was moved. This number has been established on the basis of a correlation of available full-scale airplane spin-recovery data and the corresponding model test results.

PRECISION

The accuracy of measurement of the model spin data is believed to be within the following limits:

α, deg	± 1
ϕ, deg	± 1
V, percent	± 5
Ω, percent	± 2
Turns for recovery:	
Obtained from film	$\pm\frac{1}{4}$
Obtained by visual observation	$\pm\frac{1}{2}$

In the case of spins in which it was difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin, the values presented do not necessarily represent the full range of variations because of the limitations of the methods of measurement.

Comparison of the models and the full-scale results (ref. 5) indicates that the model tests satisfactorily predicted full-scale recovery characteristics approximately 90 percent of the time. For the remaining 10 percent, about half the model results were optimistic and half were pessimistic; these results, however, were of value in predicting some of the details of the full-scale spins and recoveries. When the model spin was at an angle of attack less than 45°, the airplane spin was generally at a larger angle of attack; whereas, when the model spin was at an angle of attack greater than 45°, the airplane spin was generally at a smaller angle of attack than that indicated by the model - that is, the airplane tended to spin at an angle of attack closer to 45° than did the corresponding model. The model generally spun with a lower altitude loss per revolution than that of the corresponding airplane. The higher rate of descent of the airplane or the model, however, was generally associated with the smaller angle of attack; that is, when an airplane spun at a smaller angle of attack, it generally had a higher rate of descent than the corresponding model, and when the model spun at a smaller angle of attack, the model had the higher rate of descent. The model generally spun with more outward sideslip than did the corresponding airplane.

Because it is impractical to ballast the model exactly and because of inadvertent damage to the model during the tests, the measured weight and mass distribution of the model varied from the scaled-down values of table II within the following limits:

Weight, percent	0
Center-of-gravity location, percent $\bar{c}$	1 forward to 1 rearward
Moments of inertia:	
I_X, percent	1 low to 1 high
I_Y, percent	1 low to 1 high
I_Z, percent	0

The accuracy of measuring the weight and mass distribution of the model is believed to be within the following limits:

Weight, percent	± 1
Center of gravity, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5

The controls were set with an accuracy of $\pm 1^\circ$.

TEST CONDITIONS

Tests were made by comparing the effects of spoiler-slot-deflector lateral controls and ailerons. Two lateral-control configurations (A and B) employing spoilers and deflectors were investigated (figs. 2 and 3). The tests included the spoiler alone with and without a wing slot, the deflector alone with and without a wing slot, and a spoiler-slot-deflector combination. Configuration B was also investigated with a spoiler-slot-deflector combination with the chord of the spoiler and deflector equal to that of configuration A. Mass characteristics and mass parameters for the loading condition tested are presented in table II.

The control settings (measured perpendicular to the hinge lines) used for the investigation were:

Rudder, deg . . . . 30 right or neutral
Elevator, deg . . . . 30 up
Ailerons, deg . . . . 20 up, 20 down, or neutral
Spoilers, deg . . . . 55 up or neutral
Deflectors, deg . . . . 55 down, 27.5 down, or neutral

RESULTS AND DISCUSSION

The results of the investigation are presented in charts 1 and 2. The model data are presented in terms of the full-scale airplane values and are arbitrarily presented in terms of right-hand spins. Only elevator-up spins were investigated.

Effect of ailerons.- In order to provide a basis for the evaluation of the results with combinations of spoilers, slots, and deflectors, a series of spins were conducted in which ailerons were used as the lateral-control device. As has been stated previously, the rudder was neutralized for the recovery attempts rather than being reversed fully in order to accentuate the effect of the lateral controls. The data presented at the top of charts 1 and 2 indicate that setting the ailerons full with the spin was favorable and resulted in rapid recoveries by rudder movement to neutral, whereas with ailerons set to neutral or against the spin either the model was very slow in recovering or did not recover. This aileron effect is consistent with the information presented in reference 1 for airplane types represented by the models which have the mass largely distributed within the fuselage.

Spoiler-slot-deflector configurations A.- The results of tests with the spoiler-slot-deflector configurations A are presented in chart 1. This configuration gave good recoveries, comparable with those obtained with the ailerons. The control deflection required was such that it gave rolling moment against the spin (stick left in a right spin) in contrast to the aileron recoveries which required ailerons with the spin (stick right in a right spin). Various combinations of component positions were tried to determine their relative effectiveness. It was found that decreasing the projection of the under-surface deflector reduced the recovery effectiveness although good recoveries were generally obtained with the deflector projection cut to one-half the spoiler projection. No combination was effective unless it included deflection of the under-surface deflector. On the other hand, extension of the under-surface deflector by itself without the slot or the upper-surface spoiler gave good recoveries. It is therefore evident that substantially the entire effectiveness stemmed from the projection of the under-surface deflector.

As is indicated in chart 1, the effect of the deflectors is opposite to that produced by the ailerons in that stick right in a right spin was favorable when ailerons were used as the lateral controls (ailerons with the spin) whereas stick left in a right spin was favorable when deflectors were used for lateral control. It appears that the primary contribution of ailerons deflected with the spin is a rolling moment in the direction of the spin; this rolling moment, in turn, causes a decrease in the pro-spin, inertia yawing moment for an airplane having a large percentage of mass distributed within the fuselage (refs. 1 and 6). In addition to the rolling moment, the unpublished results of tests have indicated that the ailerons deflected with the spin also produce an aerodynamic antispin yawing moment which aids recovery. Unpublished spin-balance test results indicate that the effectiveness of the deflector in terminating the high-angle-of-attack spins attained by the present model is attributable to the antispin yawing moment produced when the deflector is projected on the outboard wing (left wing in a right spin).

Spoiler-slot-deflector configurations B.- In order to simulate more closely the spoilers and deflectors used in the investigation reported in reference 2 for which force data were available, spoiler-slot-deflector configurations B were investigated on the model and the results of these tests are presented in chart 2. The same general trends were exhibited as for configurations A, but the effectiveness of the complete configuration was adversely affected by its more forward location and the recoveries were not satisfactory. The addition of the spoiler to the deflector-slot combinations of configurations B had an adverse effect on the recoveries as is shown on chart 2.

Brief tests were made with the spoiler and deflector surfaces of configuration B modified by increasing the chord to a constant dimension equal to that of configuration A. The dimensional characteristics of the slot were unchanged and the same angular deflection was used. This arrangement did not improve the effectiveness of the spoiler-slot-deflector combination.

Unpublished force-test results have indicated that spoiler-slot-deflector configuration A was more effective than configuration B because of chordwise positioning: the unpublished results indicate that a configuration similar to configuration A provided large antispin yawing moments when the spoiler and the deflector were projected on the outboard wing (left wing in a right spin), whereas the yawing moments produced by a configuration similar to configuration B were small, particularly for angles of attack corresponding to the spinning attitude of the present model.

CONCLUDING REMARKS

For the contemporary swept-wing fighter investigated, the ailerons used as lateral controls were effective in assisting recovery from the spin when deflected with the spin (stick right in a right spin). A spoiler-slot-deflector lateral-control arrangement, located about 70 percent of the chord back of the wing leading edge, was effective when the combination was deflected against the spin (stick left in a right spin), but a similar arrangement located about 50 percent of the chord back of the wing leading edge was ineffective. Apparently, the effectiveness of any proposed spoiler-slot-deflector configuration will have to be evaluated for each configuration. The under-surface deflector was apparently the effective component of the spoiler-slot-deflector combination. Upper-surface spoilers alone or in combination with a slot offered little assistance in terminating spins.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 30, 1954.

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TABLE I

DIMENSIONAL CHARACTERISTICS OF SWEPT-WING FIGHTER

AIRPLANE REPRESENTED BY $\frac{1}{24}$-SCALE MODEL

Length, overall, ft	37.14
Wing:	
Span, ft	34.50
Area, sq ft	300
Incidence, deg	0
Dihedral, deg	0
Aspect ratio	4
Taper ratio	0.5
Leading edge $\bar{c}$, rearward from leading edge of wing at the root, ft	6.01
$\bar{c}$, ft	8.94
Sweepback at 25-percent chord, deg	35
Airfoil section	NACA 64A010
Ailerons:	
Span, ft each (parallel to Y-axis)	3.66
Horizontal tail:	
Span, ft	10.84
Total area, sq ft	41.17
Sweepback at 25-percent chord, deg	35

TABLE II

MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR

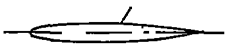
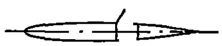
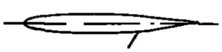
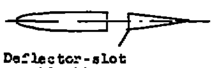
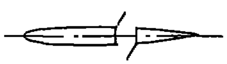
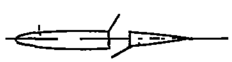
AIRPLANE REPRESENTED BY $\frac{1}{24}$ - SCALE MODEL

[Model values converted to corresponding full-scale values; moments of inertia given about the center of gravity]

Weight, lb	Center-of-gravity location		Relative density, μ		Moments of inertia, slug-ft^2			Mass parameters		
	$x/\bar{c}$	$z/\bar{c}$	Sea level	15,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
20,872	0.225	-0.009	26.32	41.84	14,712	31,133	43,765	-213×10^{-4}	-164×10^{-4}	377×10^{-4}

CHART 1.- COMPARISON OF SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH AILERONS AND WITH SPOILER-SLOT-DEFLECTOR CONFIGURATIONS A INSTALLED

[Test conditions as follows: Right erect spins; elevator full up; recovery attempted by rapid rudder neutralization unless otherwise indicated (recovery attempted from and steady spin data presented for rudder-full-with spin); lateral control arrangement as indicated]

Lateral-control arrangement	Condition	Note	α (deg)	φ (deg)	V (fps)	Ω (rps)	Turns for recovery
Trailing-edge ailerons	Lateral controls full against (Stick left)	a	64 79	10U 9D	229 257	0.37	>7, ∞
		a	53 60	7U 2D	243 270	0.32	4½, 5, 6¼
	Lateral controls full with (Stick right)	b			>326		½, 1, 1½
 Spoiler on unslotted wing	Spoiler projected on left wing	a	55 64	10U 6D	257 276	0.31	>4½, >5
	Spoiler projected on right wing	a	51 56	7U 6D	276 290	0.28	3, 5½
 Spoiler-slot combination	Spoiler projected on left wing	a			270 304		3, 4
	Spoiler projected on right wing	a	55 58	6U 9D	263 283	0.30	>5, >7
 Deflector on unslotted wing	Deflector projected on left wing	b			>326		½, ¾, 1¾
	Deflector projected on right wing	a	60 72	11U 8D	243 263	0.36	>5, >7¾, >8
 Deflector-slot combination	Deflector projected on left wing		NO SPIN				
	Deflector projected on right wing	a	56 64	8U 9D	243 270	0.33	>4, >8, ∞
 Spoiler-slot-deflector combination Deflector projection equal to spoiler projection	Deflector and spoiler projected on left wing				>326		¾, ¾, 1
		a	52 71	12U 10D	266	0.34	1[d], 1[d], 1¼[d], 1½[c,d]
	Deflector and spoiler projected on right wing	a	56 63	6U 6D	263 283	0.32	>6, ∞
 Spoiler-slot-deflector combination Maximum spoiler projection Deflector projection equal to one-half spoiler projection	Deflector and spoiler projected on left wing				276		½, ¾, 2½
	Deflector and spoiler projected on right wing	a	48 62	4U 1D	275 290	0.29	>3½, >5½

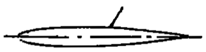
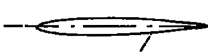
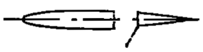
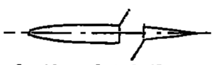
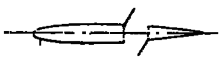
[a]Oscillatory spin, range of values given.
[b]No-spin condition also observed.
[c]Visual estimate.
[d]Recovery attempted by rudder neutralization and simultaneous deflection of spoiler and deflector to full-against spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 2.- COMPARISON OF SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL WITH AILERONS AND WITH SPOILER-SLOT-DEFLECTOR CONFIGURATIONS B INSTALLED

[Test conditions as follows: Right erect spins; elevator full up; recovery attempted by rapid rudder neutralization (recovery attempted from and steady-spin data presented for rudder-full-with spin); lateral control arrangement as indicated]

Lateral-control arrangement	Left		Neutral		Right
Trailing-edge ailerons	[a] α: 6[illegible], 79; φ: 10U, 9D; V: 229, 257; Ω: 0.37; Turns: >7, ∞	← Lateral controls full against (Stick left)	[a] α: 53, 65; φ: 7U, 2D; V: 243, 270; Ω: 0.32; Turns: $4\frac{1}{2}$, 5, $6\frac{1}{4}$	Lateral controls full with (Stick right) →	[b] V: 326; Turns: $\frac{1}{2}$, 1, $1\frac{1}{2}$
 Spoiler on unslotted wing	[a] α: 54, 61; φ: 10U, 4D; V: 243, 276; Ω: 0.31; Turns: $5\frac{3}{4}$, $6\frac{3}{4}$	← Spoiler projected on left wing		Spoiler projected on right wing →	[a] α: 49, 64; φ: 10U, 12D; V: 257, 312; Ω: 0.30; Turns: $>3\frac{1}{2}$, >4
 Spoiler-slot combination	[a,c] α: 61, 65; φ: 8U, 8D; V: 236, 290; Ω: 0.36; Turns: >7, >8	← Spoiler projected on left wing		Spoiler projected on right wing →	[a] α: 51, 54; φ: 4U, 2D; V: 270, 304; Ω: 0.29; Turns: [d] >6, [d] >6
 Deflector on unslotted wing	[e] V: App. 353	← Deflector projected on left wing		Deflector projected on right wing →	[d] α: 52, 58; φ: 4U, 4D; V: 257, 290; Ω: 0.31; Turns: >8, ∞
 Deflector-slot combination	[a] α: 52, 55; φ: 4U, 0; V: 257, 326; Ω: 0.30; Turns: $2\frac{1}{4}$, $2\frac{1}{2}$, 3	← Deflector projected on left wing		Deflector projected on right wing →	[a] α: 60, 66; φ: 9U, 5D; V: 243, 270; Ω: 0.33; Turns: >7, >7
 Spoiler-slot-deflector combination	[a] α: 56, 74; φ: 8U, 9D; V: 257; Ω: 0.39; Turns: >8, $>8\frac{1}{2}$	← Deflector and spoiler projected on left wing		Deflector and spoiler projected on right wing →	[a] α: 50, 55; φ: 7U, 4D; V: 257, 290; Ω: 0.30; Turns: $>4\frac{3}{4}$, $>6\frac{1}{2}$
 Spoiler-slot-deflector combination Chord of spoiler and deflector equal to chord for configuration A	[a,c] α: 58, 72; φ: 10U, 9D; V: 260; Ω: 0.38; Turns: $5\frac{3}{4}$, $6\frac{3}{4}$, $9\frac{3}{4}$	← Deflector and spoiler projected on left wing			

[a]Oscillatory spin, range of values given.
[b]No-spin condition also observed.
[c]Wandering spin.
[d]Visual estimate.
[e]Steep, wandering spin -- recovery data not obtainable.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

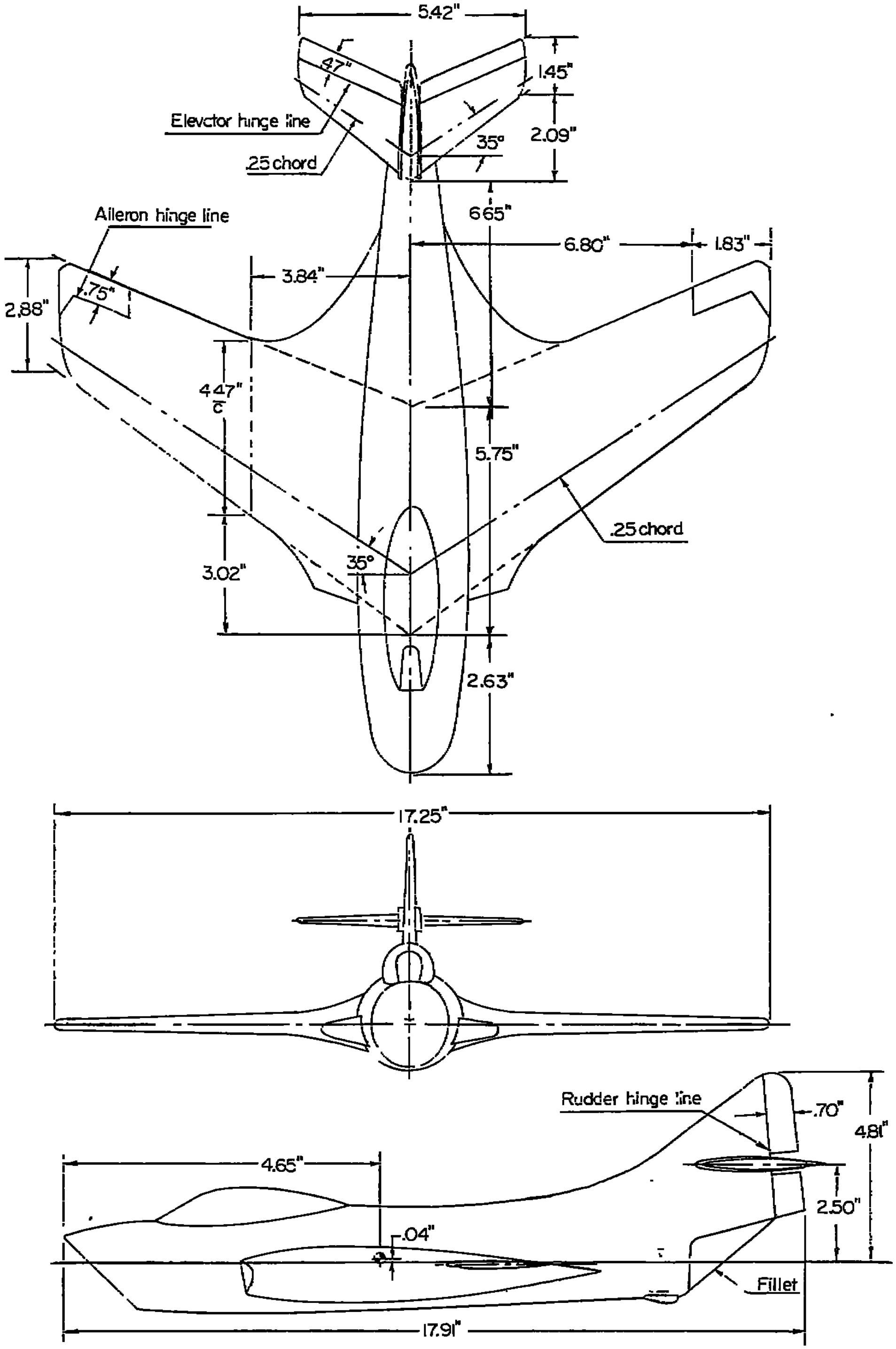


Figure 1.- Three-view drawing of assumed 1/24-scale model used in investigation.

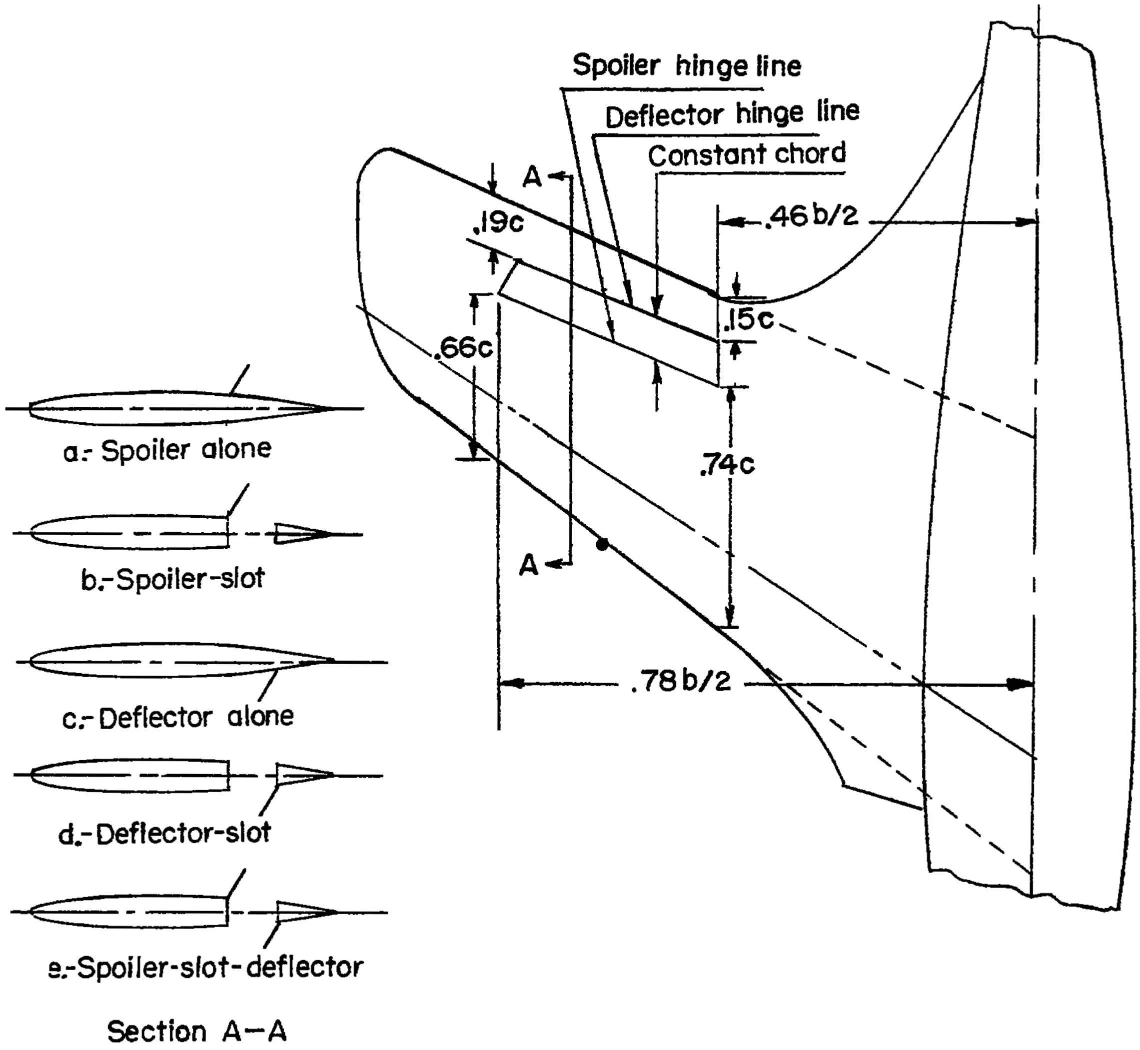


Figure 2.- Spoiler-slot-deflector configurations A investigated on model.

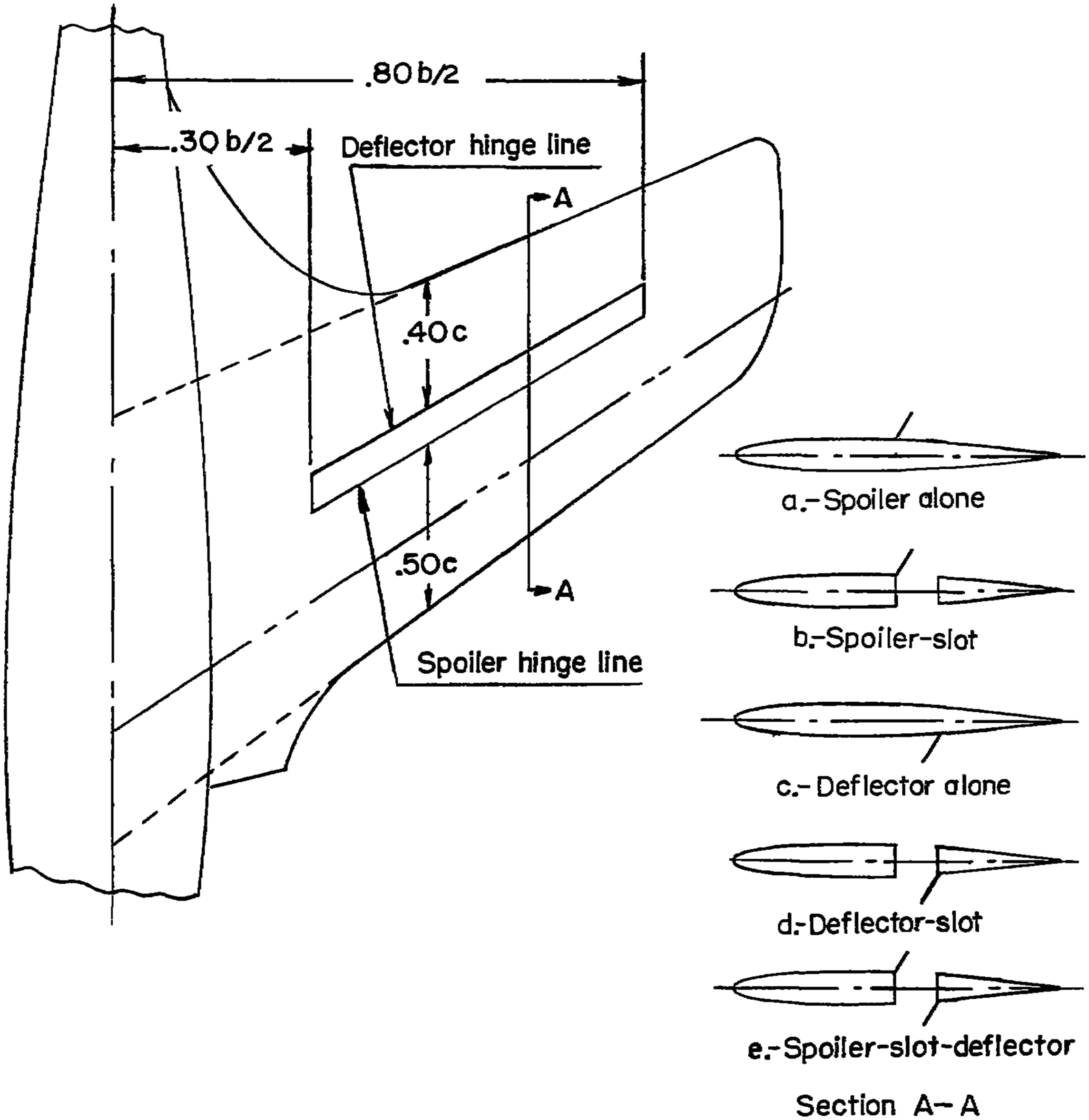


Figure 3.- Spoiler-slot-deflector configurations B investigated on model.

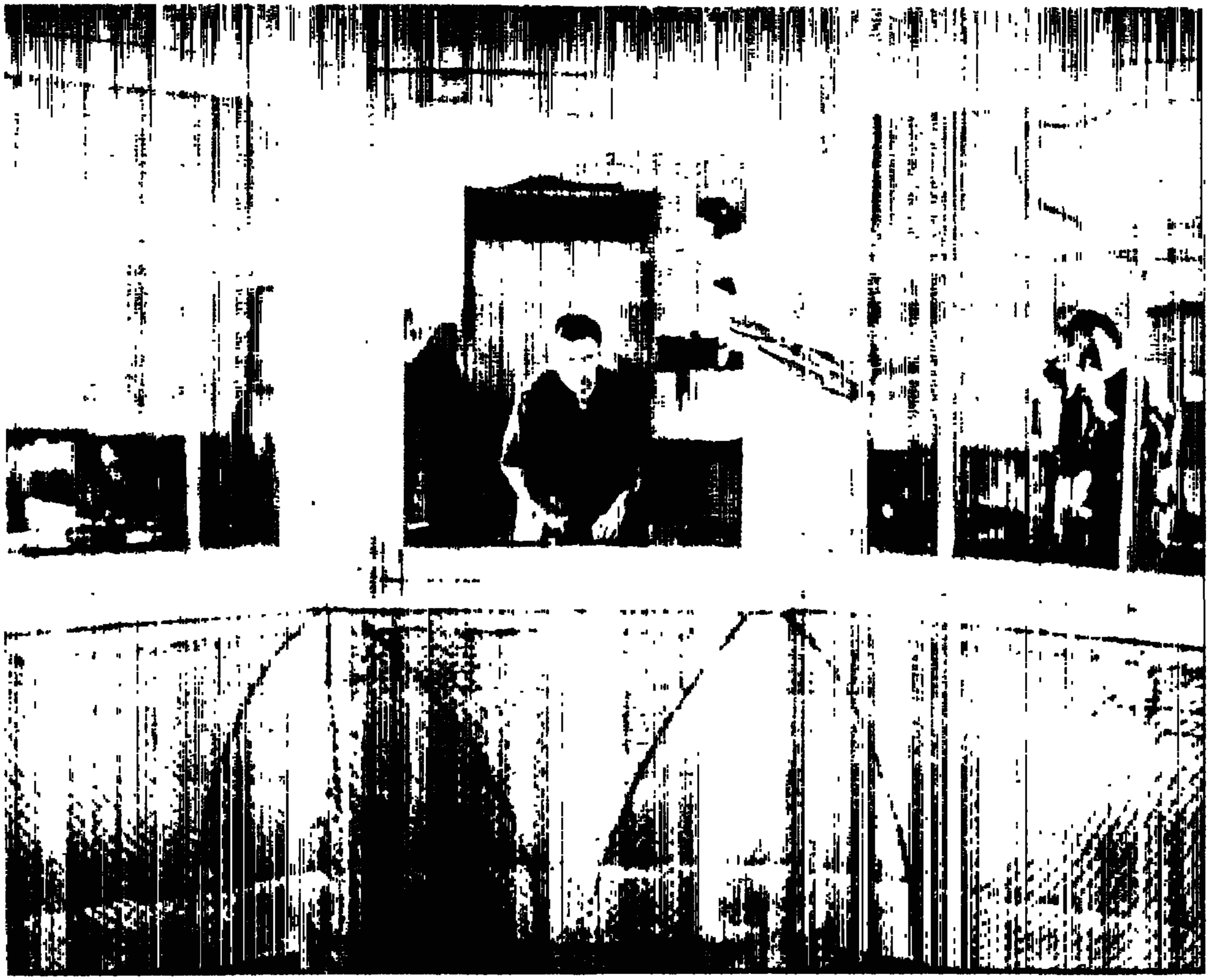


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Figure 4.- The model spinning in the Langley 20-foot free-spinning tunnel.

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